SPATIAL ECOLOGY of EurOPEAN badgers (Meles meles) in Mediterranean habitats of the North -Eastern Iberian Peninsula. II: HABITAT SELECTION

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VIE ET MILIEU - LIFE AND ENVIRONMENT, 2009, 59 (2): 233-242

SPATIAL ECOLOGY OF EUROPEAN BADGERS (*MELES MELES*) IN MEDITERRANEAN HABITATS OF THE NORTH-EASTERN IBERIAN PENINSULA. II: HABITAT SELECTION

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EUROPEAN BADGER
HABITAT SELECTION
IBERIAN PENINSULA
MEDITERRANEAN HABITATS
MELES MELES

ABSTRACT. – The adaptability of badgers to diverse environments under conditions of variable food availability (amount and variety) together with their social organization patterns have allowed them to inhabit a vast geographical range across Europe. Consequently, badger habitat selection has been addressed throughout most of its distribution range in terms of both individual ranges and sett locations. Several versions of the Resource Dispersion Hypothesis have been proposed to explain habitat selection by badgers. Here we performed a compositional analysis to evaluate the habitat preferences of badgers in the NE Iberian Peninsula. For this purpose, we used data from the radio-tracking of 13 adult individuals in two Natural Parks near Barcelona (at home range and core foraging area scale), and also the location data of 39 setts in one of these parks. At the home range level, badgers selected mainly riparian vegetation habitats and avoided residential areas. Similar results were also obtained from the sett environment analysis. However, badgers chose crop fields for core foraging areas. In accordance with previous findings, our results show that badgers in Mediterranean environments choose habitats on the basis of the capacity of these to provide protective shelter rather than on food availability where food is not a critical, limiting resource in the badger environment. We conclude that the same habitat characteristics are chosen for both sett sites and home ranges while agricultural patches define core foraging areas. These results are in accordance with the Sett Dispersion Hypothesis.

INTRODUCTION

The European badger has a wide distribution across Europe (Johnson *et al.* 2002), encompassing a broad range of environments and ecological conditions (e.g. Kowalczyk *et al.* 2003, Kauhala *et al.* 2006, Revilla *et al.* 2000). As a result, badgers are highly adapted to exploiting resources and to living under diverse conditions (weather, vegetation coverage, human disturbance, etc.). Consequently, these animals show high variability in population densities and in their pattern of trophic resource exploitation (niche width, food specialist *vs* food generalist). In addition, they show a variable social organization across their distribution range (Palphramand *et al.* 2007), from groups of up to 25 individuals in England (Rogers *et al.*1997) to solitary individuals in a Mediterranean habitat in Italy (Pigozzi 1987). Moreover, the nocturnal and secretive habits of the badgers allow them to coexist with man to a limited extent. Badger burrows, called setts, which are central to the group's social life, are also a key resource for the species (Doncaster & Woodroffe 1993, Roper 1993). Like most species, the requirements for food, shelter and other resources are expected to shape badger habitat selection in such a way that the use of habitat types deviates from their proportional availability. Some habitats are selected because they provide these resources while others are avoided because they offer no advantage or adversely affect badger settlement.

Habitat selection by the badger in its European distribution range has been studied in a variety of environments. These include habitats as diverse as grasslands or meadows (northeast England, Palphramand *et al.* 2007; Italian Alps, Prigioni *et al.* 2008) arable lands (southeast England, Delahay *et al.* 2006) and woodlands (northern Italy, Balestrieri *et al.* 2006; Swiss Jura Mountains, Do Linh San *et al.* 2007a, Do Linh San *et al.* 2007b suburban; Tokyo, Kaneko *et al.* 2006). In Mediterranean environments, which have a more sclerophyllous xeric vegetation, badgers select habitats comprising Mediterranean shrubs (Revilla *et al.* 2000, Mangas *et al.* 2008), riparian woods (Virgós 2001a), ash tree forests (Virgós & Casanovas 1999) or cork oak woods (Rosalino *et al.* 2004, Rosalino *et al.* 2008). The high badger population densities found in the rainy habitats of the British Isles characterized by a relatively low seasonal differences in the precipitation regime, have been typically associated with the abundance of earthworms in meadows and pastures (Kruuk & Parish 1981). In contrast, in Mediterranean habitats, badgers are not earthworm specialists because of their low availability (Virgós 2001b), but mainly ingest fruits and also prey on a variety of items (insects, snails, earthworms and small vertebrates, Rosalino *et al.* 2005b). In our study areas, crop fields occur in a patchy agricultural mosaic included in the forest matrix. These habitats allow badgers to feed on a variety of cultivated plants (fruits and vegetables) and also on the invertebrate fauna associated with these environments. Therefore, *a priori*, these habitats are ideal foraging grounds because they provide food all year round.

There is consensus that badger groups need enough underground space in order to fulfil several basic functions: 1) Hygienic: sett alternation to reduce ecto-parasite load (Broseth *et al*. 1997a, Butler & Roper 1996); 2) Reproductive: isolation of some individuals from others during the breeding season for reproductive success (Cresswell *et al*. 1992); 3) Energetic: daytime resting sites (Kruuk 1989) or overwintering shelters (Fowler & Racey 1988); and 4) Security: shelter to reduce the risk of predation (Butler & Roper 1995) and human disturbance (Jenkinson & Wheater 1998). The density, location and habitat features of badger setts are among the most widely studied characteristics of badger ecology across its European distribution range (Bartmanska & Nadolska 2003, Do Linh San *et al*. 2007a, Fischer & Weber 2003, Good *et al*. 2001, Kowalczyk *et al*. 2000, Macdonald *et al*. 2004, Moore & Roper 2003, Pavlacik *et al*. 2004, Rogers *et al*. 2003, Roper 1992, Roper *et al*. 2001, Roper & Moore 2003, Wilson *et al*. 2003) including Mediterranean habitats (Loureiro *et al*. 2007, Remonti *et al*. 2006, Revilla *et al*. 2001, Rosalino *et al*. 2005a). Habitat type is the main factor that determines sett location in the English badger (Huck *et al*. 2008). Moreover, the characteristics of the sites selected for sett establishment also vary across its distribution range, from pasturelands and hedgerows in Ireland (Hammond *et al*. 2001, Feore & Montgomery 1999) to under tree-cover areas in Italy (Remonti *et al*. 2006), or Mediterranean scrubland in the south of the Iberian Peninsula (Revilla *et al*. 2001).

The Resource Dispersion Hypothesis (RDH) proposes that group-living may be a consequence of resource exploitation patterns (see a recent revision in Macdonald *et al*. 2004). Therefore, the social organization of badgers will be determined by the heterogeneous distribution of patchy resources and by the richness of the patches. The proposed limiting resources on which territory configuration hinges have typically been two: food resources (Food Dispersion Hypothesis, FDH), and suitable sites at which badgers can build a sett (Sett Dispersion Hypothesis, SDH). The relative importance of food patch distribution and availability of sett sites varies between populations and it is therefore difficult to compare their respective effects since the two factors are expected to act together (da Silva *et al*. 1993). Under some circumstances, the optimality of badger foraging regimes (energy budgets) could be compromised in order to take advantage of suitable sett sites, so far as ultimate energetic constraints permit. When outside the sett, they are expected to spend most of their time foraging in areas that include the habitat patches where they preferentially feed. If food patch dispersion determines the home range configuration, as predicted by the FDH, one would expect badgers to select the same habitat types for home ranges as for core foraging grounds. However, if suitable sites for sett location determine home range configuration (Johnson *et al*. 2002), as predicted by the SDH, one would expect a high proportion of sett habitat types within the home range and a positive selection for these habitats.

The present study describes the key habitat types used by badgers for territory settlement (home range), foraging (core foraging areas), and sett sites in two Mediterranean study areas. We aim to: 1) assess which of the proposed hypotheses best fits the situation of the badger populations in two environments that are subjected to high levels of human pressure and habitat fragmentation; and 2) identify the most important habitats for badgers in the study areas in order to improve species management and habitat preservation programmes.

MATERIALS AND METHODS

Study Area: The Collserola Park (41º27'N, 2º6'E) comprises 85 km^2 and belongs to the Catalan Coastal Cordillera, which spreads over about 100 km in a North-South direction, parallel to the Mediterranean Sea, roughly 10 km away from the coastline. Altitudes range from 50 to 512 m above sea level and the mean yearly rainfall during the study period was 672 mm, with wide seasonal variations. Summer is usually the hottest and driest season (13.2ºC-30.9ºC), whereas spring (3.8ºC-23.3ºC) and autumn (6.5ºC-24.2ºC) are the wettest ones and winters are mild (0.3ºC-17.6ºC). The inner 80 % of the Park are covered by dense woodland, largely dominated by the Aleppo pine (*Pinus halepensis*) and the holm oak (*Quercus ilex*). The Park contains a dense network of temporary streams, most of which are dry year round, except for brief periods after intense rain. The riparian woods are made up of elms (*Ulmus campestris*) and poplars (*Populus alba* and *P. nigra*), but most of them are in a poor state of conservation and the river beds and their surroundings slopes are populated by dense blackberry (*Rubus ulmifolius*), sarsaparilla (*Smilax aspera*) and patchy reed (*Arundo donax*) communities. The periphery of the Park is formed by more gently slopes, except the one facing Barcelona, and the vegetation is mostly scrub patches of tree heath (*Erica arborea*), strawberry tree (*Arbutus unedo*), rock rose (*Cistus* ssp), mastic tree (*Pistacia lentiscus*), holly oak (*Quercus coccifera*) and Spanish broom (*Spartium junceum*), depending on the orientation of the slope. These peripheral areas hold most of the little agricultural activity remaining in Collserola, mainly allotments, orchards and cereal fields (8 % of its surface). For a complete description of the Park, see Cañas (1995). It is important to note that although the Collserola Park is almost completely isolated from other natural surroundings by the city-belt, and accordingly some areas of Collserola can be classified as sub-urban habitats, most of the Park remains a wild natural environment.

The second study area is located on the southern side of the Montserrat Mountain Natural Park and its agricultural surround-

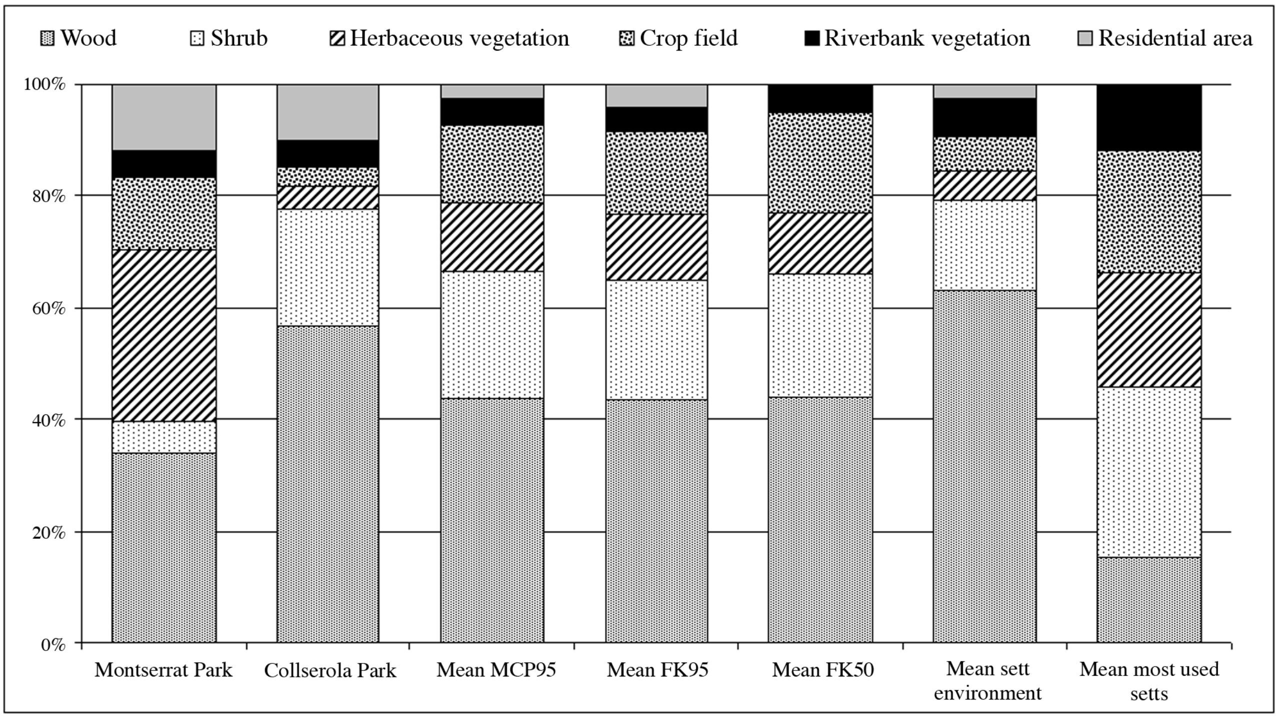

Fig. 1. – Habitat percentages of the 3 radio-telemetry study areas, home range average for MCP95 and FK95, average of core areas (FK50), for the habitats available in the Collserola Park, the average for the 39 sett environments and the average of the 9 most used setts.

ings (41°36'N, 1°48'E), 16 km apart from Collserola Park. The altitudes of the Montserrat massif range from 250 to 1224 m. The climate is typically Mediterranean, similar to that of Collserola, but dryer and hotter on the southern side. The most common tree species is the Aleppo Pine (*Pinus halepensis*) and herbaceous vegetation is abundant. This cover alternates with olive crops (*Olea europaea*) near the mountains on the north-eastern side and vineyards (*Vitis* sp.) and cereal crops on the south-western side. The typical coastal holm oak wood is abundant at low altitudes. Contrary to the Collserola Park, Montserrat is an open and less fragmented area. Indeed, in general terms, Montserrat is patchier and has more agricultural and herbaceous areas and fewer forest areas and shrubs than the Collserola Park (Fig. 1).

Trapping and radio-tracking: Collserola is a long-term study site while Montserrat was added as a short-term comparison. Trapping took place between 1997 and 2006 in Collserola and in 1999-2000 in Montserrat. Badgers were captured with padded leg-hold traps (Victor Soft Catch 1.5, Woodstream Corp. Lititz, PA) following the Recommendations of the Animal Welfare Protocol of the European Union. No badger was injured during handling. Badgers were anesthetized by intramuscular injections of combinations of ketamine and xylazine hydrochloride (Kreeger 1997) or diazepam and medetomidine (Palphramand *et al*. 2007). Only adults (6 males and 5 females in Collserola, and 2 males and 2 females in Montserrat, Table I) were equipped with a radio-transmitter (TW-5, Biotrack Ltd). The radio-signal of two males from Collserola was lost just after release or after a short period of time and was never found again. We used a portable VHF receiver (R1000, Communications Specialists Inc) and a hand-held three element Yagi antenna (Biotrack Ltd) to collect radio-tracking data. We recorded all bearings for each radiolocation within a 10-minute interval to reduce the error associated with badger movement and within 45-135° intervals for crossing bearings. Radio-tracking data and spatial estimators were calculated with Ranges VII software (South *et al*. 2005).

Habitat classification: On the basis of Catalonian type of cover digital cartography (CREAF), six habitat types were distinguished in our study areas: riverbank vegetation (RV); pine woods and oak tree woods (W); shrub (S); crop field (C); herbaceous vegetation (HV); and residential areas (RA; Table I). Pine and oak tree habitats were merged into a woodland habitat association because oak wood rarely occurs alone but mixed with pine. Urban nuclei, transport networks (railways, roads and highways) and industrial estates were excluded from the analyses because they were considered unsuitable habitats for badgers. We conducted ground surveys and comparisons with digitized aerial photographs to ensure that we correctly classified polygons into each habitat class. Special attention was given to small orchards, which are sometimes omitted from standard cartography.

Data analysis: From 1997 to 2007, the spatial behavior of 13 badgers was studied by means of radio-tracking: 2 males and 2 females in Montserrat (M1, M2, F3 and F4), and 4 males and 5 females in Collserola (F5, F6, M7, F8, F9, M10, M11, F14 and M15). Home range and core foraging areas were used to define the habitat polygons in each study area using ArcView GIS 3.2

Table I. – Correspondence between habitat associations, areas included and plant communities.

Habitat association	Vegetation units	Main species included
Riverbank vegetation (RV)	5 m buffer around water streams 10 m buffer around 1st class rivers 15 m buffer around 2nd class rivers	*Rubus fructicosus, Smilax aspera, Arundo donax, Phragmites australis*
Woodland (W)	Pine-dominating wood	*Pinus halepensis, Pinus pinea*
	Esclerophite-dominating wood	*Quercus ilex, Quercus coccifera*
	Deciduous-dominating wood	*Quercus pyrenaica, Quercus suber*
Crop field (C)	Fruit trees	*Prunus dulcis, Ceratonia siliqua, Olea europaea*
	Irrigated fruit trees	*Ficus carica, Prunus avium*
	Vineyards	*Vitis* ssp.
	Dry grass crops	*Hordeum vulgare*
	Irrigated grass crops	*Medicago sativa*
	Small orchards	A variety of fruit and vegetable species
Shrub (S)	Bush-dominating wood	*Bupleurum fruticosum, Calicotome spinosa, Cistus monspeliensis, Cistus salviifolius, Rosmarinus officinalis, Erica multiflora, Genista scorpius*
	Makis-dominating wood	*Quercus coccifera, Chamaerop humilis, Ceratonia siliqua, Rhamus alicoides*
	Wood with poor vegetation coverage	*Erica arborea, Lavandula stoechas, Pistacia lentiscus, Smilax aspera, Quercus coccifera*
Herbaceous vegetation (HV)	Meadow-dominating vegetation	*Hyparrhenietum hirto-pubescens*
Residential areas (RA)	Neighborhoods of variable extension inside the Park	Same as woodland and shrub habitats
Not included (NI)	Urban	Urban nucleus
	Transport infrastructures	Areas occupied by motorways and roads
	Industry	Areas occupied by factories and industrial areas

(ESRI, 1992) and to produce the data for calculating the proportional area of habitat classes (Brunjes *et al*. 2006). For home range estimators, we used the *Minimum Convex Polygon* with 95 % of fixes (MCP95) and *Fixed Kernel* with 95 % of fixes (FK95, Worton 1989). For fixed kernel estimates, an optimal smoothing parameter (*h*) was created for each home range (Kenward *et al*. 2001) by multiplying the smoothing parameter found by minimum squares method (*hcv*) by a correcting factor by trial and error. This correcting factor was found by intervals of 0.01 starting in 1 *hcv*. We accepted the smoothing parameter resulting in the smallest FK95 that allowed a single shape as a home range, avoiding unconnected patches (Bonet-Arbolí 2003). For core foraging areas, we used only *Fixed Kernel* with 50 % fixes (FK50) because MCP distinguishes only one concentric core area patch per home range, which is incongruous with the movements of each individual observed. In order to avoid pseudoreplication, overlapping home ranges were merged to make the compositional analyses (M2+F4 in Montserrat and F5+F6 in Collserola).

Compositional analysis (Aebischer *et al*. 1993) was used to study badger preferences of habitat use by replacing all non-used habitat types by a value of 0.03 (Brennan 2004). We assessed habitat selection at 2 hierarchical orders based on badger behavior, which we adapted from Johnson (1980). To evaluate second order habitat selection, the composition of habitats within home ranges (MCP95 and FK95) was compared with that of habitats within the corresponding study area. As a third order habitat selection, we compared the composition of habitats within core foraging areas (FK50) with that of habitats within the corresponding home range (Beasley *et al*. 2007), but avoiding the less preferred habitat resulting from the second order analysis (Aebischer *et al*. 1993). However, for third order analysis, we used the individual core foraging areas because, only in one case, did the core areas of two individuals partially overlap. For sex and Park comparisons, we used simple MANOVA with log-ratios (Aebischer *et al*. 1993). To set the limits of a study area, a Fixed Kernel with 99 % of the distribution of all fixes merged for all badgers in each study area was drawn with a 500 m buffer around it (Lamberti *et al*. 2006). Habitat attributes were exported to DBASE IV files and used to obtain the proportions of each habitat class in each of the three study areas by means of ArcView GIS 3.2 (ESRI, 1992). To carry out compositional analyses, an Excel (Microsoft, Redmond, WA) macro was used (Smith 2005).

The badger population: We obtained a mean home range of about 300 ha for males and 80 ha for females, varying slightly depending on the estimator used (MCP95 or FK95). In Collserola, males had ranges over four times larger than those of females, while male badgers captured in Montserrat exhibited a 1.5 fold range over females. Estimated population densities were 0.6 individuals/km^2 for Collserola and 1.9 ind./km^2 for Montserrat, and badger groups were formed by 1-2 individuals and 1-3 individuals respectively (Molina-Vacas *et al*. 2009). According to our calculations, based on sett and camera-trapping surveys we estimated that 40-50 % of the resident badgers in the study areas of both parks were tracked. Indeed, this represents 15 % of the population of the whole Collserola Park. However, as Montserrat is an open environment, we cannot precisely ascertain the percentage of the population tracked. The highly populated urban nuclei which surround Collserola Park come to over 4 million people, this high human pressure involves a high influx of people in the Park which means higher levels of badger sett disturbance by humans and domestic animals (loose and abandoned dogs), and an increase of poaching and road-kill risk.

Sett environment selection in the Collserola Park: From 1992 to 1995, we carried out several surveys with the help of volunteers and Park keepers to find the largest possible number of badger setts in Collserola Park. A total of 151 badger burrows were found, 52 of which were subsequently monitored weekly during several 3-month periods in 1995 and 1996 by means of field-sign surveys, so that an activity status (i.e. active/non active) could be ascribed to each sett for each week. Six setts were monitored during the eight periods, while the remainders were monitored for 1-7 periods (85 % being monitored for 5 or more periods). Burrows that were found to be in use for at least one week (n = 26, Bonet-Arboli 2003) were then selected for compositional analyses together with 8 setts used by the radio-tracked individuals during the 1997-2007 period, and 5 additional setts, which were not monitored or used by the radio-tracked badgers but which showed signs of recent use when found. Thus the total sample included 39 setts. The median number of sett entrances was 3 (range 1-15). The habitat of a sett was defined by creating a 50 m-radius circle around each sett barycentre (Kaneko *et al*. 2006), and establishing habitat coverage categories on the basis of the same classification used for individual home range analysis (Table I). The habitat percentages derived were then compared with the composition of the Collserola Park (as available habitat) using compositional analyses (Aebischer *et al*. 1993).

For sett habitat selection analysis, a third order compositional analysis was performed using the habitat composition of the 39 badger setts as available habitat and that of the most used setts as the habitat selected. Log-survivor curves separated those setts monitored with high activity levels (> 30 % weeks) from those of low activity on the one hand, and those with low changing rate (< 15 % of weeks with a different status from the preceding week) from those with a high changing rate. Setts with high activity and a low changing rate (n = 4) were then considered the "most used setts". For more details on these analyses see Bonet-Arboli (2003). In Collserola, each badger uses several setts during a given year (2-9, Bonet-Arboli 2003) and shows a clear preference for one ("preferred sett"), which is used for more than 40 % of the days. Five out of the 8 radio-tracking setts included in the second order analysis were preferred setts and were thus included in the 'most used setts' category. Thus the total sample was 9. For this analysis, we avoided the least used habitat type resulting from the first order analysis, as recommended by Aebischer *et al*. (1993).

RESULTS

Individual foraging habitat selection

Considering all the home ranges (n = 11) and comparing their habitat composition with the percentages of the available habitat (second order analysis), we detected a habitat selection different from availability (non random) from both methods with the same selection sequence (MCP95: $\lambda = 0.096$, $P < 0.001$, d.f. = 5, $n = 11$, FK95: $\lambda = 0.24$, $P = 0.007$, d.f. = 5, $n = 11$), the preferred habitat being riverbank vegetation, followed by woodland, shrub, crop field and herbaceous vegetation. Residential areas were the least used habitat. Significant differences in the preference order were found between residential areas and all other habitats, except for herbaceous vegetation (Table II). No significant difference in habitat selection was found between parks (MCP95: $F = 1.719$, $P = 0.283$; FK95: $F = 2.824$, $P = 0.140$). When comparing individual core foraging areas with the corresponding home ranges (third order analysis), and after removing residential areas from the analysis, we found a significant habitat selection for all badgers (FK50: $\lambda = 0.287$, $P = 0.003$, d.f. = 4, $n = 13$). Crop fields were the preferred core foraging habitat, followed by woodland, shrub, and riverbank vegetation. Herbaceous vegetation was the least used habitat, with significant differences between crop field and all other habitats, except for shrubs (Table II). In contrast to the second order analysis, at the third level, badgers showed a preference for crop fields (mainly small orchards, vineyards and fruit tree plantations) over woodlands or riverbank vegetation. This observation indicates that crop fields contribute to determining foraging patterns. No differences in habitat selection were found between the parks ($F = 1.294$, $P = 0.350$) or between sexes ($F = 3.236$, $P = 0.074$).

Sett habitat selection in Collserola Park

We also found a significant selection concerning sett environments ($\lambda = 0.394$, $P = 0.001$, d.f. = 5, $n = 39$), the preferred habitat being riverbank vegetation again, followed by woodlands, crop fields, herbaceous vegetation and shrubs. Residential areas were the least used habitat. Significant differences between woodlands and the four habitats ranking lowest as well as between riverbank vegetation and the same four habitat types were found; bad-

Table II. – Simplified ranking matrices obtained with compositional analysis by a) comparing proportional habitat use within MCP95 with the proportion in the corresponding study area; b) *idem* with FK95; c) comparing proportional habitat use within core foraging area (FK50) with the proportion in the corresponding home range (FK95) d) comparing used habitat around Collserola setts with the proportion in the Collserola Park; and e) comparing used habitat around 9 more used setts with used habitat around Collserola setts. +++ and --- show positive and negative significant difference respectively between habitat types (P < 0.05), and + and - no significant.

a) MCP95 *vs*. Study Area	RV	W	S	C	HV	RA	Rank
Riverbank vegetation (RV)		+	+	+	+	+++	5
Woodland (W)	-		+	+	+	+++	4
Shrub (S)		-	-	+	+	+++	3
Crop field (C)	-	-	-		+	+++	2
Herbaceous vegetation (HV)	-	-	-	-		+	1
Residential area (RA)	---	---	---	---	-		0
b) FK95 *vs*. Study Area	**RV**	**W**	**S**	**C**	**HV**	**RA**	**Rank**
Riverbank vegetation (RV)		+	+	+	+	+++	5
Woodland (W)	-	+	+		+	+++	4
Shrub (S)	-		+	-	+	+++	3
Crop field (C)	-	-	+	-		+	2
Herbaceous vegetation (HV)	-	-		-	-	+	1
Residential area (RA)	---	---	-	---	-		0
c) FK50 *vs*. FK95	**C**	**W**	**S**	**RV**	**HV**		**Rank**
Crop field (C)		+++	+	+++	+++		4
Woodland (W)	---		+	+	+		3
Shrub (S)	-	-		+	+		2
Riverbank vegetation (RV)	---	-	-		+		1
Herbaceous vegetation (HV)	---	-	-	-			0
d) 39 setts *vs*. Collserola Park	**RV**	**W**	**C**	**HV**	**S**	**RA**	**Rank**
Riverbank vegetation (RV)		+	+++	+++	+++	+++	5
Woodland (W)	-		+++	+++	+++	+++	4
Crop field (C)	---	---		+	+	+++	3
Herbaceous vegetation (HV)	---	---	-		+	+++	2
Shrub (S)	---	---	-	-		+	1
Residential area (RA)	---	---	---	---	-		0
e) 9 setts *vs*. 39 setts	**RV**	**S**	**HV**	**C**	**W**		**Rank**
Riverbank vegetation (RV)		+	+++	+	+++		4
Shrub (S)	-		+	+	+		3
Herbaceous vegetation (HV)	---	-		+	+		2
Crop field (C)	-	-	-		+		1
Woodland (W)	---	-	-	-			0

gers also showed a significant preference for crop fields and herbaceous vegetation over residential areas (Table II).

In addition, a significant difference in habitat selection between the complete data-set of the 39 surveyed setts and the 9 most frequently used setts was detected ($F = 4.111$, $P = 0.005$). Thus we conducted a further analysis for these 9 setts and obtained evidence of a marginally significant habitat selection ($\lambda = 0.151$, $P = 0.053$, d.f. = 4, $n = 9$). Riverbank vegetation was again the preferred habitat type, but with shrub habitat ranking second and woodland habitat as the least used. Significant differences were also found between riverbank vegetation as compared to woodland and herbaceous vegetation (Table II).

DISCUSSION

Habitat selection

Badgers show a preference for woodland habitats in many regions of Europe (Broseth *et al.* 1997b, Do Linh San *et al.* 2007a, Kowalczyk *et al.* 2003, Palphramand *et al.* 2007), Japan (Kaneko *et al.* 2006), and also in some Mediterranean areas (Balestrieri *et al.* 2006, Rosalino *et al.* 2004). Similarly, in central Iberian Peninsula, badger abundance is positively correlated with deciduous woods and mountain pastures (Virgós & Casanovas 1999). In Mediterranean habitats, the woodland matrix contributes to food resources because of the abundance of insects (Rosalino *et al.* 2005c) and the presence of carob beans (*Ceratonia siliqua*) or wild fruit trees and shrubs (e.g. *Arbutus unedo*) scattered in the matrix. However, in our study areas, badgers selected riverbank vegetation in the second order analysis, while woodland ranked second in the second and third order analyses. In addition, given that the woodland habitat in the Collserola and Montserrat Parks includes coniferous and deciduous trees, usually mixed in an intricate matrix, we could not easily differentiate between preferences for each wood type.

However, as predicted *a priori* for our study areas, core foraging areas comprised more crop fields than expected from their abundance in home ranges. This observation implies that badgers spend most of their active time and effort foraging in or near crop fields. Our finding confirms the relevance of mosaic environments comprising crop fields interspersed with small woods, shrubby banks or small streams and fallow lands for badger foraging activity in Mediterranean environments (Rosalino *et al.* 2004). Moreover, in our study areas, most crop fields are artificially irrigated year round, thereby allowing badgers to feed on the invertebrate fauna associated with damp environments, in addition to cultivated fruits and vegetables. Although a systematic study of badger diet has not been performed in our study areas, an analysis of stomach contents of badgers killed on roads collected across Catalonia (32 000 km^2), a region in which our study areas are located, showed a dominance of fruits and insects (Corral-Bistué 2002), as it is the rule for most of the Iberian Peninsula (Melis *et al.* 2002, Rosalino *et al.* 2005c). Superficial examination of many badger faeces in the field indicated a similar diet in our study areas (authors' observation), although a rigorous diet study is required to ascertain the link between diet and foraging habitats.

At the second order of analysis, a significant avoidance of residential areas was detected for both home range and sett environments, as reported in other studies (Balestrieri *et al.* 2006, Do Linh San *et al.* 2007a, Kaneko *et al.* 2006). This observation indicates that despite the badger's well-known tolerance of human proximity (Davidson *et al.* 2008, Remonti *et al.* 2006), it does not select residential areas as suitable habitats. This strategy could be explained by the poor food or shelter resources that these habitats offer and by the presence of loose dogs, which increases the risk of predation and sett disturbance. Moreover, road traffic accidents would be more probable near residential areas due to a higher vehicle transit. Similarly, the herbaceous vegetation habitat plays a minor role for home range and core foraging areas. Pastures are important foraging areas for badgers at higher latitude/altitude with wetter environments because of the abundance of earthworms (Kruuk & Parish 1981). However, in our study areas, at low-altitude, herbaceous vegetation is the driest habitat and holds few trophic resources for badgers.

Sett environment selection

In the British Isles and Ireland, where pastureland is the dominant land-use type, and which is food productive for badgers (in terms of earthworm abundance), setts are more abundant in pastures (Hammond *et al.* 2001) or in hedgerows, woodlands and shrubs, but also near pasturelands (Feore & Montgomery 1999). In contrast, in NW Italy, badgers preferentially select woods and shrubs to build their setts (Remonti *et al.* 2006), as reported in Mediterranean habitats of the South Iberian Peninsula, where scrub zones are the sites for sett location (Revilla *et al.* 2001). However, in our study areas, badgers selected riverbank vegetation for sett location (second order analysis). Moreover, this habitat type was also the environment in which the most frequented setts, which had three times more active entrances that the remaining 30 setts, were preferentially located (third order analysis), while the woodland habitat was avoided. The profile of river banks, which present more of a cross-section, afford badgers an easier digging opportunity than the flatter conditions in woodland areas. Moreover, riverbanks are the most concealed and least accessible sites of Collserola Park, with heights ranging from 2-3 m up to about 30 m and widths of about 2-3 m up to 10-20 m steep slopes (with a mean slope angle between 45-80 degrees), and they hold higher and thornier vegetation cover, thereby hindering incursions by humans. Indeed, after the last five decades of increasing human population growth, particularly around Collserola, our results indicate that the most suitable habitats for sett location are the roughest ones while the most open habitats (residential, crop and herbaceous) rank third or lower in first and second order analyses.

Explanatory hypothesis

In the study areas, riverbank vegetation was selected for sett location in both first and second order analyses as well as for home range habitat (second order analysis) but not for core foraging areas, where it ranked fourth (out of five habitats considered). This observation implies that the same habitat features are taken into account by badgers when establishing a territory as when deciding where to dig a sett. Moreover, the finding that a distinct (agricultural) environment was selected for foraging suggests that the selection of riverbank vegetation at the home range level is not related to feeding strategies. Thus food may not be the sole factor that determines home range configuration and sett site availability may be a limiting resource for badgers (Rosalino 2005b), thereby supporting the SDH (Doncaster & Woodroffe 1993), at least in low density populations subjected to high human pressure (habitat degradation in quality, quantity and connectivity, and also direct persecution) in the Mediterranean area.

Nevertheless, the possibility that riverbank vegetation is chosen for distinct reasons for home range establishment and sett digging cannot be disregarded. For example, the need for shelter and steep slopes is the strongest factor explaining the importance of riverbank vegetation for building setts. However, shelter could also be a critical factor in the habitat composition of home ranges. The branching nature of these riverbank habitats allows badgers to move unnoticed across their home ranges, as occurs in scrub habitat in Brighton, UK (Davidson *et al.* 2009). Therefore, the shelter provided by riverbanks could explain their first rank in the habitat preference order in home ranges, independently of the need for shelter around sett sites.

Finally, the observation that factors other than food availability explain habitat selection at the home range level does not imply that food distribution is not important during home range establishment but rather that the effect of the availability of refuges on the configuration of the home range depends on shelter availability in each environment. To occupy a given territory, badgers need rich food patches (crop fields and adjoining environments in our case) with nearby refuges for protection (riverbank vegetation). In high density badger populations, like those found in the UK, food resources are the main limiting factor for home ranges (Macdonald *et al.* 2004). In contrast, in our low density populations, badgers showed strong shelter requirements because of human disturbance (hunting, poaching, road-kills, loose dogs).

Conservation of badgers in Mediterranean habitats

In our study areas, badgers live at low densities, in social groups of 1-3 individuals (Do Linh San *et al.* 2007a, Revilla *et al.* 2001), as expected for a region with dry and markedly seasonal weather conditions (Johnson *et al.* 2002). Furthermore, due to the dense human population around the study areas (especially in Collserola), badgers live under great human pressure. Given the marked habitat preference of badgers for riverbank vegetation and traditional agricultural environments, the promotion and maintenance of these areas should be a priority in the design of management plans for these mustelids. Furthermore, riparian habitats are also used by other mammals inhabiting the two Parks, such as the red fox and wild boar (authors' unpublished data). This observation highlights the importance of this habitat type for wild mammal preservation. Managers and Park authorities should therefore pay particular attention to the preservation of these degraded riparian habitats, rather to restore them to their primeval state when promoting suitable habitats for these species.

Acknowledgements. – We are grateful to two anonymous referees for comments on an earlier version of the manuscript, which helped to improve it. We thank the Collserola Park for financial support and the Barcelona Zoo and Can Balasch Biological Station for veterinary and logistical support. VBA and ERP were granted fellowships from the "Generalitat de Catalunya" during part of the work. We also thank A Barroso and the Montserrat Mountain Park guards for their help with the trapping and radio-tracking tasks. Badgers were trapped and manipulated with permission of the "Departament de Medi Ambient i Habitatge" of the "Generalitat de Catalunya", the Ethical interuniversity Commission of Catalonia, the Park authorities and hunter associations. The English version of this manuscript has been revised by Robin Rycroft from the UB's Linguistic Advice Service.

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Received October 30, 2008
Accepted January 7, 2009
Associate Editor: A Chenuil